

FINAL REPORT

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Title: Interannual Variability of Snow and Ice and Impact on the Carbon Cycle
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The goal of this research is to assess the impact of the interannual variability in snow/ice using global satellite data sets acquired in the last two decades. This variability will be used as input to simulate the CO₂ interannual variability at high latitudes using a biospheric model. The progress in the past few years is summarized as follows.

Albedo Decrease Related to Spring Snow Retreat

We study the impact of the spring snow retreat on albedo from 1979 to 1991 using the ultraviolet (UV) reflectivity measured by the Total Ozone Mapping Spectrometer (TOMS). Over the Northern Hemisphere (NH) land area that was snow covered at least once during this period, we find a 1.5% decrease over the 13 years in the springtime UV reflectivity, related to a 5×10^6 km² decrease in the satellite derived spring snow cover. About half of the albedo decrease occurred over regions that snow cover and albedo correlate at a 99% significance level. The 1.5% UV reflectivity decrease corresponds to a 1% decrease in the visible albedo over the snowy region, and 2 Wm⁻² increase in the shortwave heating over the NH land area. Based on observed interannual reflectivity changes over the NH snow covered land area, our study provides a direct constraint on the shortwave forcing of the spring NH snow retreat. The reprint may be viewed in <http://yly-mac.gps.caltech.edu/> under "Snow-ice Papers".

Observed effects of interannual summertime sea ice variations on the polar reflectance

Using the Total Ozone Mapping Spectrometer (TOMS) measurements, we show that ultraviolet Lambertian equivalent reflectivity (UV LER) variations of the polar icy areas are well correlated with the microwave-derived sea ice concentration variations on interannual timescales. The effect of interannual sea ice variations on the UV LER appears to have a hemispheric asymmetry: a 1% change in the sea ice concentration is related to a larger UV LER change in the Antarctic ($0.59 \pm 0.09\%$) than in the Arctic icy areas ($0.35 \pm 0.05\%$). This result is extended to the top of the atmosphere (TOA) broadband visible albedo by relating the UV LER to the TOA albedo. The observed asymmetry is absent in a general circulation model that we have examined. The preprint may be viewed in <http://yly-mac.gps.caltech.edu/> under "Snow-ice Papers".

The Northern Annular Mode response to Arctic sea ice loss and the sensitivity of troposphere-stratosphere interaction

The response of the Northern Hemisphere climate to the total loss of Arctic sea ice is explored with an atmospheric general circulation model to further the understanding of its influence on upper-tropospheric and stratospheric conditions. The atmospheric response of sea ice removal is most substantial in the wintertime. The lower troposphere is 8-12 K warmer due to increases in sensible heating and longwave emission from the surface, and leads to a mean flow anomaly that corresponds to an annular mode index of -1.8. The spatial structure of the leading mode of variability in wintertime displays more zonal symmetry and has less covariance with variability in the North Atlantic. Reduced wind shear and stability provide reduced baroclinicity, and consequently reduced synoptic scale variability. With changes in tropospheric wave activity and the mean state, the amplitude of the leading mode is reduced by around 15%. The leading mode of variability in the stratosphere is also more symmetric and more closely coupled to the troposphere, even though the downward adjustment to variations in the stratospheric vortex is reduced. The reduction in wave activity gives reduced dissipation of easterly momentum in the stratosphere and acts to reduce the stratospheric overturning and the poleward transport of heat and mass. Consequently, there is less polar ozone, which would act to further increase the weak negative longwave radiative feedback at high latitudes. Should the sea ice be lost over the course of the twenty-first century, the recovery time for polar ozone in the absence of anthropogenic chlorine emissions will be extended. The preprint may be viewed in <http://yly-mac.gps.caltech.edu/> under "Snow-ice Papers".

The effect of Arctic warming and sea ice loss on the growing season in northern terrestrial ecosystem

High-latitude regions are particularly sensitive to climate change, with warming over three times the global mean expected in the twenty-first century. One aspect of polar climate that can exacerbate Arctic change is the sea ice state. Here the impact of sea ice loss on Arctic warming and growing season length was evaluated using an atmospheric general circulation model. High-latitude change in a simulation representative of 2080 conditions with enhanced greenhouse forcing was contrasted with change deduced from a simulation in which only the sea ice state was degraded. In winter, sea ice loss advanced the timing of minimum temperature and promoted heating of the atmosphere by the ocean. Because of this, high-latitude terrestrial ecosystems experienced earlier thaw (by 7-10 days), however, only with enhanced greenhouse forcing did the summer maximum temperature increase and did the onset of freezing become substantially delayed. Warmer Arctic conditions decreased variations in surface air temperatures associated with both storminess and the diurnal cycle at the onset of the growing season. This further increases the length of the growing season by reduction in the vulnerability to early season bud development. Manuscript in preparation. See attached file in Appendix.

Publications Supported by this Grant

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Noone, D., 2003, Sensitivity of the vertical coupling of Northern wintertime annular modes to anomalous high-latitude surface heating, Research Activities in Atmospheric and Oceanic Modelling, J. Cote (Ed.), Report No. 33, World Meteorological Organization, 4.19-4.20

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Contribution to Human Resources

David Noone was supported by this grant. He is now an assistant professor at the University of Colorado.

Zhiming Kuang's thesis was partially supported by this grant. He is now a NOAA Global Change Fellow at the University of Washington.

Z. M. Kuang, I: Remote Spectroscopic Measurements of Atmospheric HDO/H₂O and Column CO₂, II: Interannual Variations of the Earth's Reflectance, 2003, California Institute of Technology.